*Sustainable Design Series of Delft University of Technology*

# Bamboo

## a Sustainable Solution for Western Europe Design Cases, LCAs and Land-use

Pablo van der Lugt
Joost Vogtländer
Han Brezet

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a Sustainable Solution for Western Europe
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*Key words*: life cycle analysis, bamboo.

# Foreword

The need for sustainable development becomes urgently evident. This is caused by our continuously increasing consumption levels, resulting in a rising pressure on our global resources, and visible through the various financial, food and climate crises around the world. At the supply side, the use of fast growing sustainably produced renewable materials such as bamboo can help to meet this increasing demand.
Life Cycle Assessment (LCA) is used in this report to compare the environmental impact of bamboo materials in Western Europe with commonly used materials such as timber.

This is partly an updated version of the environmental assessments made in the PhD thesis "Design Interventions for Stimulating Bamboo Commercialization"[1] by Pablo van der Lugt. The thesis was written as part of the Design for Sustainability Program at the Faculty of Industrial Design Engineering at Delft University of Technology in the Netherlands. The work was supervised by Prof. dr. Han Brezet, while the environmental assessments were executed in close collaboration with Dr. Joost Vogtländer.
The data used in this report are slightly modified compared to the eco-costs calculations executed in the PhD thesis. The new data are based on the latest updates of the IDEMAT-2008 and Ecoinvent-V2 databases, from which the eco-costs/kg from the material alternatives have been derived.
Furthermore, some additional modified wood alternatives (Plato® wood and Accoya®) were added to the environmental assessment for the functional unit "terrace decking" in Section 2.6.

The report is targeted towards any stakeholder in the bamboo or wood production chain that wants to get a better understanding of the environmental sustainability of bamboo materials compared to alternatives. The environmental assessment also provides insight in the impact of each step in the production process on the overall environmental sustainability of a material. As a result, the supplier of the bamboo materials assessed, Moso International BV, has improved the production process of several of their bamboo materials (for details see Section 2.3).

Chapter 1 sketches the rationale of this research, providing the importance of sustainable development, the impact of materials on the environmental sustainability and the potential of renewable materials - and in particular bamboo - for sustainable development, leading to the objective of this report: to assess the environmental

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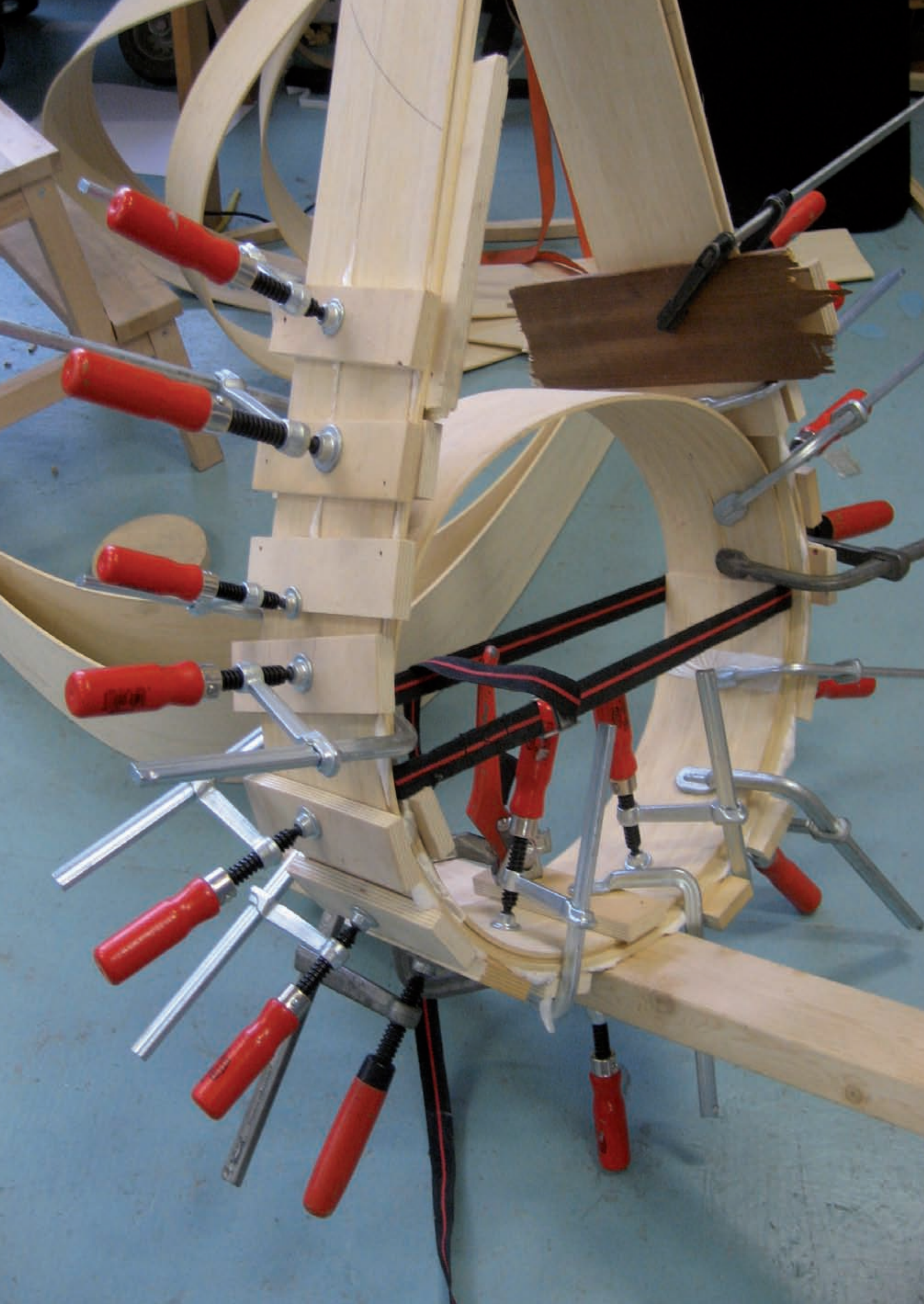
1 Available via http://www.vssd.nl/hlf/m015.htm and most (online) bookstores (ISBN 978-90-5155-047-4), or downloadable via http://www.library.tudelft.nl/ws/search/publications/search/metadata/index.htm?docname=381757

sustainability of bamboo materials in Western Europe compared to alternative materials. Chapter 2 provides the results of the environmental assessment in so called "Eco-costs" based on the negative environmental effects caused during the production of bamboo materials. Since the regenerative power of renewable materials is also an important environmental sustainability criterion which is not included in the LCA-based Eco-costs model, in chapter 3 the annual yield of bamboo materials is compared with several timber alternatives. Chapter 4 combines the results of chapter 2 and 3 to come to an overall conclusion about the environmental sustainability of bamboo materials based on current use in Western Europe, current use in the bamboo producing countries themselves and the future use of bamboo materials. Finally, in chapter 5, several recommendations are provided for further research as well as practical recommendations to the bamboo industry how to improve the environmental sustainability of their materials.

At this particular place I would like to thank director René Zaal of Moso International for the support and transparency in providing accurate production data which facilitated a comprehensive and complete assessment of the various bamboo materials. Furthermore I would like to thank my co-authors Dr. Joost Vogtländer and Prof. dr. Han Brezet for their support during my research process as well as in writing this report.
I sincerely hope that this report helps to further increase knowledge amongst stakeholders in the bamboo industry that bamboo materials are not always - as often unfoundedly claimed - the best environmental benign alternative around. This is only the case when several parameters, as presented in this report, are met, which may help shape policy objectives and suggestions for production improvements in the bamboo industry. May this report serve as a stepping stone toward this goal.

Delft University of Technology, The Netherlands, March 2009
Pablo van der Lugt
Joost Vogtländer
Han Brezet

# Contents



# 1 Introduction

## 1.1 Sustainable Development

Because of the growing human population on our planet in combination with an increase of consumption per capita, more and more pressure is put on global resources, causing the three main interrelated environmental problems: depletion of resources, deterioration of ecosystems and deterioration of human health, and their effects (see Table 1.1). Starting in the 1970s through the alarming warning from the Club of Rome, public awareness about the environment has increased drastically over the last decades. In 1987 the World Commission on Environment and Development headed by Brundtland presented the report Our Common Future (Brundtland et al. 1987) including the - now widely adopted - concept of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Although the report also emphasized the importance of decreasing the differences in wealth between developed countries in the "North" and developing countries in the "South", through a better balance in economy and ecology, the term "sustainability" was first mostly interpreted in its environmental meaning.

| Depletion of resources | Deterioration of ecosystems | Deterioration of human health |
|---|---|---|
| Exhaustion of raw materials | Climate change | Ozone at living level |
| Exhaustion of fossil fuels | Erosion | Summer smog |
| Exhaustion of food & water | Landscape deterioration | Winter smog |
| | Desiccation | Noise hindrance |
| | Ozone layer deterioration | Stench hindrance |
| | Acidification | Light hindrance |
| | Nuclear accidents | Indoor pollution |
| | Eutrofication | Radiation |
| | Hazardous pollution spread | Spread of dust |

Table 1.1: The three main environmental problems including their effects (adapted after van den Dobbelsteen 2004)

| Resource | Fossil fuel reserves left based on most optimistic estimates (production years to go before depletion) |
|---|---|
| Oil | 45 years |
| Gas | 72 years |
| Coal | 252 years |

Table 1.2: Depletion of resources - consumption and reserves of fossil energy (EIA 2007)

The Brundtland Commission also introduced the factor thinking linked to the idea of sustainable development: to give future generations the same opportunities as mankind has today, present consumption needs to be reduced by a factor of 20 compared to the reference year 1990. This number - which has been largely adopted in environmental policy making - is based on reducing the global environmental burden by half, while anticipating a doubling of the world's population and a five-fold increase of wealth per capita due to increasing consumption especially by emerging economies (van den Dobbelsteen 2004).

Recent targets set by the European Union for the reduction of greenhouse gases are based on a reduction by half the emissions of 1990 in 2050 (and a 20% reduction in 2020).

Although the attention for the environment is improving (e.g. the EU greenhouse emission targets), the factor 20 environmental improvement has not come closer at all. There is a strong debate going on about strategies on the global level, about how to meet these environmental goals (e.g. Cradle to Cradle philosophy by McDonough and Braungart (2002)). However, environmental problems such as climate change have only increased since Brundtland introduced the term sustainable development. This is caused, amongst others, by the increasing globalization, including the more active involvement of new emerging economies such as India and China in the global marketplace. This leads to an increase in wealth and consumption per capita of these densely populated countries.

Most environmental strategies do not yet follow an integrated approach and do not take the three main environmental problems into account in a holistic manner. For example, the acclaimed Cradle to Cradle strategy by McDonough and Braungart (2002) focuses on the re-use of raw materials, but less on energy required during this process (e.g. for recycling and transport).

Due to the increasing globalization, economic and social components were integrated in the term sustainability. These social-economic components are related to human rights, minimization of child labor, health & safety in the workplace, governance and management, transparency and the abolition of corruption and bribery. Although globalization can potentially lead to more equality worldwide, the outsourcing of (production) activities to low income countries has in general led to the opposite, which has driven Non Governmental Organizations (NGOs), pressure groups and governments in the West to actively put sustainability in its broad form (including the social and economical component) on the agenda, resulting in an increasing emphasis on sustainable consumption and entrepreneurship.

This can be noticed in the adoption of new corporate policies by various multinationals (e.g. Corporate Social Responsibility - CSR), new business models such as the Base of Pyramid approach (Prahalad and Hart 2002), and the increasing establishment of certification schemes for products (e.g. FSC for sustainably produced wood, MSC for sustainable fish, UTZ for sustainable coffee ). Companies adopting these policies and

certification schemes guarantee that along the complete value chain[2] environmental, social and economical requirements with respect to sustainability are met (OECD 2006). Many cases in the media have shown that especially in the South, in which environmental and social aspects have often never been taken into account previously in business activities, it is very difficult to meet sustainability requirements (e.g. the various reports of production of clothing for the West in sweat shops in Asia).
The social, environmental and economical components of sustainability are usually referred to as "People" (the social component), "Planet" (the environmental component) and "Profit" (the economical component). These three pillars of sustainability are also referred to as "the Triple Bottom Line" (Elkington 1997).
In this report, the focus is on the environmental component ("Planet") of sustainability.

## 1.2 The Impact of Materials on the Environmental Sustainability

The environmental impact of a product depends on all the life cycle stages of the product. Intuitively one expects that the environmental impact of a material has the most influence on the production phase of a product caused by raw material provision and factory production. However, the choice for a specific material in a product also has a strong and direct impact on other aspects of the product in other stages of the life cycle, such as the processing stage (e.g. impact on energy impact and efficiency of production technology), use phase (e.g. durability during life span) and the end-of-life phase (e.g. possibility of recycling, biodegradation, or generation of electricity at the end of the life span). This shows that materials are intrinsically linked to every stage of the life cycle of a product.
If we look at the three main environmental problems introduced in Table 1.1, the important role of materials on the environment also becomes evident:

### 1.2.1 Depletion of Resources

The use of materials contribute to the depletion of resources. Through the extraction of renewable biotic (e.g. timber), finite abiotic (e.g. minerals, oil) raw materials, as well as through the consumption of fossil fuels. It becomes clear that resource depletion is becoming an urgent problem for society. The raw material consumption of industrial-

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2 The value chain model was first introduced by Michael Porter (Porter 1985) to analyze the competitive position of a firm in an industry. Since then the model has been widely adopted and further developed over the decades. Kaplinsky (2000) provides the following definition: "The value chain describes the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use." In each link of the value chain activities are deployed, which require specific knowledge and equipment that add value to the product. Value chains consist of many links that usually represent different companies.

ized countries per capita is high. It lies in the range of 45-85 tons per year[3] [4] (Adriaanse et al. 1997, Dorsthorst and Kowalczyk 2000), and is expected to grow further (a factor 20, as explaned before) due to the transition of emerging economies (e.g. India, China[5]). Man is extracting more resources than planet Earth can regenerate. A useful indicator, which makes this deficit quantifiable in numbers, is the Ecological Footprint, which is defined as "a measure of how much biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates using prevailing technology and resource management practices" (WWF International 2006). The Ecological Footprint also includes global food-, water- and energy production, including the required capacity to absorb the wastes and environmental pollution.

In 2003 the Ecological Footprint was 14.1 billion global hectares, whereas the productive area was 11.2 billion global hectares, which means man is currently consuming more than 1.25 times the amount of resources the earth can produce. With the earlier mentioned population and consumption growth projections, the Ecological Footprint is set to double[6] by 2050 (WWF International 2006). For some time the earth can cover this global "ecological deficit" or "overshoot" by consuming earlier produced stocks. However, when these stocks run out, various resources will become scarce which may result in resource based disasters and conflicts. To bring the Ecological Footprint to a sustainable level, measures should be taken on both the demand and supply side (see Figure 1.1). On the demand side the global population, the consumption per capita and the average footprint capacity per unit of consumption (i.e. amount of resources used in the production of goods and services) determine the total demand of resources. At the supply side the amount of biologically productive area, and the productivity of that area, determine the amount of resources that can be produced globally to meet this demand.

### 1.2.2 Ecosystem Deterioration

Next to resource depletion, the high raw material requirements of industrialized countries also impact ecosystems, since these raw materials need to be extracted (e.g. landscape deterioration, erosion), processed and transported (e.g. emissions of greenhouse gases causing climate change), and ultimately disposed of as waste (e.g. toxification, acidification). Depending on the material in question the influence of the extraction and manufacturing of materials on ecosystem deterioration will differ. For

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3 For example, in Japan 14 tons of ore and minerals needs to be mined and processed per capita annually to meet demand for cars and other other metal-intensive products (Adriaanse et al. 1997).

4 In the building industry in the Netherlands alone, 120 million tons of raw materials are required annually (Dorsthorst and Kowalczyk 2000), of which at least 86% needs to be primary (van den Dobbelsteen 2004).

5 For example, in China in the coming decade around 400 million new houses need to be built in the countryside, which if built in the traditional brick rural housing type would deplete 25% of China's top soil layer of agricultural land, not even taking into account the enormous amount of coal required for brick production (McDonough and Braungart 2002).

6 Note that in late studies (Nguyen and Yamamoto 2007) the Ecological Footprint is adjusted to also include consumption of abiotic resources, revealing even larger problems with respect to resource depletion than the original method.

example, heavy metals may have a stronger environmental impact during the use and end-of-life phase due to their toxicity and the lack of biological degradability of these materials. Also biotic raw materials such as timber will - in the case of unsustainable management - damage the ecosystem from which the wood is harvested.

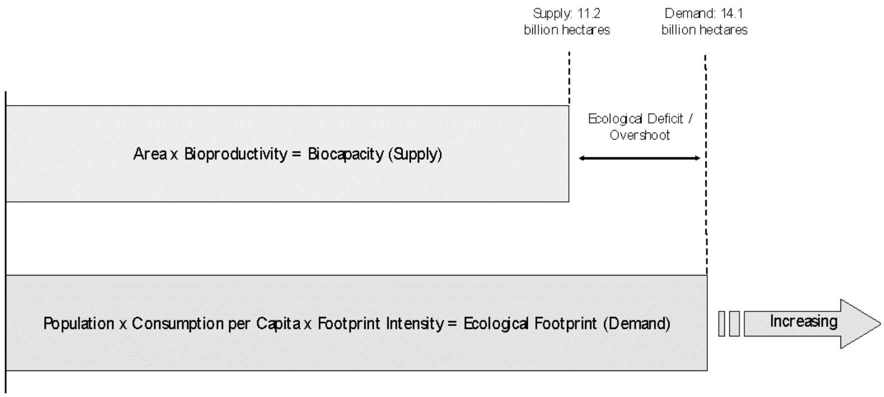


Figure 1.1: Gap between supply and demand between bioproductivity and Ecological Footprint (Figure adapted after WWF International 2006)

### 1.2.3 Deterioration of Human Health

Some materials, such as the earlier mentioned heavy metals, can be harmful to human health. Also, biotic materials such as timber can be harmful to human health, for example, when they are impregnated with poisonous preservatives (e.g. arsenic, copper, chrome) for a longer life span of the timber.

From the above it becomes clear that directly or indirectly, materials have a large influence on the environmental impact of products, now and in the future. Although the social component of sustainability lies outside the scope of this report, it is important to understand that many raw materials are extracted in developing countries and emerging economies and - in the case of local value addition through processing and product development - yields many opportunities for socio-economic development locally, potentially contributing to sustainable development. However, most value addition to materials still takes place in developed countries (e.g. luxury products).

## 1.3 The Potential of Renewable Materials

Above, the important impact of materials on the environmental burden of products was explored. One of the main strategies toward environmental improvement with respect to material use during product development is the deployment of renewable materials. This has also been proposed in the Design for Environment (DfE) strategy wheel (DfE strategy one) by Brezet and van Hemel (1997), and the Three Step Strategy[7]

[7] The Three Step Strategy entails the following steps to increase a more conscious use of our resources (Duijvestein 1997):

developed by the research group Urban Design and Environment at Delft University of Technology (DUT). Due to the increasing depletion of finite abiotic raw materials, renewable resources are gaining an increasing amount of attention, since they enable the demand for materials in a potentially sustainable manner.

However, besides for input in raw material production, renewable resources may also be used for food or energy production (biomass, biofuel). As a result, the available 11.2 billion global productive hectares compete with each other to produce either food, energy or raw materials, which has led to much controversy worldwide. Using available global hectares for the production of natural crops for biofuels impedes the use of these crops for food (or raw material production), which has resulted in strong upward pressure on food prices worldwide (Worldbank 2008). Furthermore, recent studies (e.g. Searchinger et al. 2008) indicate that in some cases biofuels, stimulated in various governmental policies because of their presumed ability to reduce emission of greenhouse gases, may even increase emission of these gases on the global level, since conversion of forests and grasslands to cropland cause additional emissions. This example shows that renewable resources are not 'automatically' environmentally sustainable. Global synchronized policies are required, to make sure that the available productive hectares will meet the future global demand for food (and water), energy and raw materials.

For raw material production, wood has always been the best known renewable material. However, because of the high rate of harvesting from available forests worldwide, this renewable resource is under a lot of pressure and with continued unsustainable extraction it can be considered a finite resource as well.

Below, the state of the art of available forest resources is summarized, and the potential of other renewable materials, such as bamboo, is reviewed.

### 1.3.1 Wood as a Renewable Material

Wood is derived from forests. The total area of forests worldwide is estimated to be just below 4 billion hectares, of which around 0.7-1.3 billion hectares is actively involved in wood production (FAO 2006). For centuries, the total area of forest worldwide has decreased steadily. Although deforestation still continues at an alarmingly high rate of 13 million hectares annually, due to natural expansion, plantation development, and landscape restoration, the net loss of total forest areas in the period from 2000-2005 is "only" 7.3 million hectares per year (almost twice the size of the Netherlands). This means that the net loss of forest area is decreasing compared to the periods before, with a net loss of forest area of 15.6 million hectares annually from 1980-1990 and 8.9 millions of hectares per year from 1990-2000 (FAO 2001, FAO 2006).

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1. Avoid unnecessary demand for resources
2. Use resources that are unlimited or renewable
3. Use limited resources wisely (cleanly and with a large return)

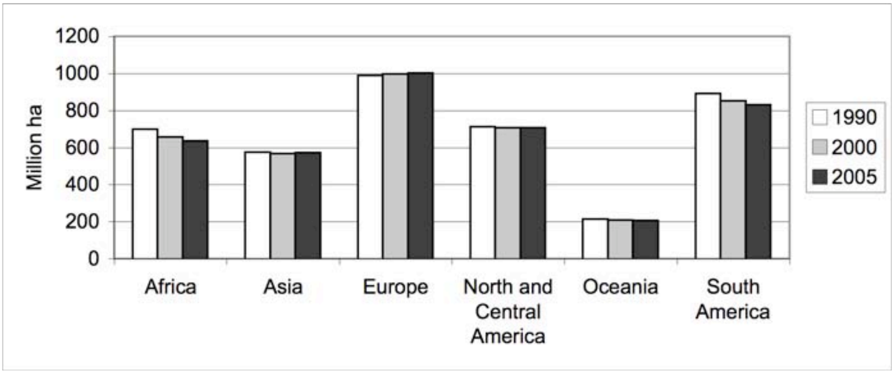


Figure 1.2: Trends in forest area by region[8] 1990-2005 (FAO 2006)

Besides the development of new plantations (+2.8 million hectares per year in 2000-2005), natural expansion, and landscape restorations, another cause of the decrease in net forest loss is the increase of sustainable forest management practices in which the forest from which the wood is derived is kept largely intact. Various schemes exist certifying the sustainability of the chain of custody of wood products. The Program for the Endorsement of Forest Certification schemes (PEFC) and the Forest Stewardship Council (FSC) schemes are most popular in the EU and the USA. The PEFC scheme mostly presumes coniferous wood, whereas FSC has a relatively large share of certified tropical forest. Demand of certified wood is strongly growing, especially in North America and the EU. This is mainly due to the strong lobby of public organizations, NGOs and governments, driven by the growing importance of sustainability. Besides the Planet component, the People and Profit elements of sustainability are also of importance in sustainable forest management certification schemes. The total area of certified forest in 2007 is estimated at just over 300 million hectares (with only 8% in (sub)tropical regions), with a growing rate of approximately 10% annually (Centrum Hout 2007).

Although the total area of certified forests is growing, the availability of certified wood is low. This is because the demand is very high and is expected to remain growing. The result is high prices of certified wood. A global market survey by FSC reported demand exceeding supply by at least 10 million cubic meters of round wood for hardwood (FSC 2005).

FSC wood requires complex logistics and management systems, needed to ensure system integrity.

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8 FAO (2006) included Northern Asia in the region of Europe (see Figure 1.1 on page 8 in the Global Forest Assessment 2005) explaining the high forest area in Europe as a relatively small continent in Figure 1.2.

Table 1.3: Certified forest area worldwide per certification scheme, million ha (Centrum Hout 2007)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|
| FSC | 22.17 | 24.10 | 31.07 | 40.42 | 46.94 | 68.13 | 84.29 | 90.78 |
| PEFC | 32.37 | 41.06 | 46.31 | 50.85 | 54.96 | 185.16 | 193.82 | 196.00 |
| SFI | 11.33 | 22.00 | 32.37 | 41.36 | 45.59 | > PEFC | > PEFC | > PEFC |
| ATFS | - | - | 10.50 | 10.50 | 10.50 | 10.50 | 10.50 | 10.50 |
| CSA | 5.03 | 5.94 | 14.44 | 28.41 | 47.38 | > PEFC | > PEFC | > PEFC |
| MTCC | - | - | - | - | 4.74 | 4.79 | 4.73 | 4.73 |
| Other | - | - | - | - | - | 1.18 | 1.19 | 1.18 |
| Total | 70.90 | 93.10 | 134.69 | 171.54 | 210.11 | 269.76 | 294.53 | 303.19 |

FSC - Forest Stewardship Council; PEFC - Program for the Endorsement of Forest Certification schemes; SFI - Sustainable Forestry Initiative; ATFS - American Tree Farm System; CSA - Canadian Standards Association; MTCC - Malaysian Timber Certification Council. In 2005 SFI and CSA were integrated in the PEFC system.

### 1.3.2 The Situation in (sub)Tropical Areas

From Figures 1.2 and 1.3 it becomes clear that while the total forest area increases or stabilizes in more temperate regions (North America, Europe, Northern and Central Asia), in tropical regions around the equator in general the forest area still decreases. This is a problem since the forests with the most biodiversity and biomass per hectare are located mostly in this (sub)tropical area (FAO 2006). Deforestation, especially of tropical forests, is therefore also a major contributor to carbon dioxide emissions, accounting for around 20% of total emissions worldwide (Knapen 2007).

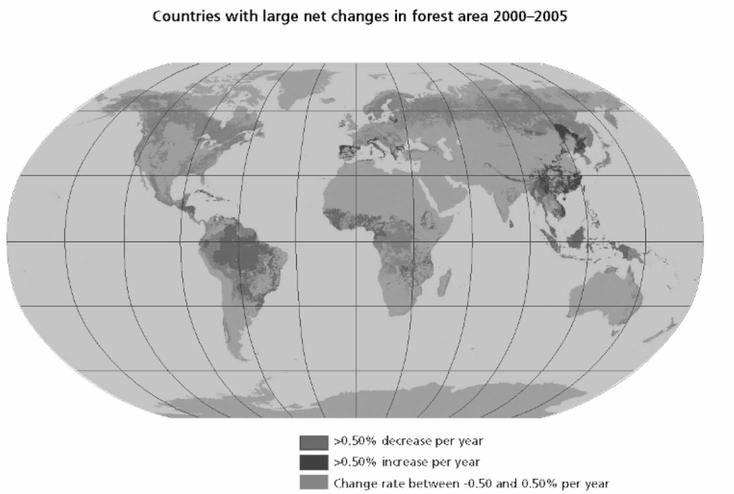


Figure 1.3: Changes in forest area worldwide 2000 - 2005 (FAO 2006)

The causes of tropical deforestation are complex and many. Various studies show that although wood production is an important factor in deforestation, deforestation is mostly caused by slash-and-burn agriculture by poor peasants looking for new ground and fuel wood, permanent agriculture (mainly converting forest in grasslands for cattle breeding) and the development of large civil and infrastructural projects (van Soest 1998). Depending on the region, the importance of these causes may differ. Van Soest

(1998) finds that depending on the region, wood production may account for approximately 10-20% of tropical deforestation, while the conversion of forest into agricultural land is perceived as the most important direct cause of tropical deforestation, of which slash-and-burn agriculture and permanent agriculture may account for up to 40% each. The conversion of forest into crop or cattle land is a good example of the Ecological Footprint becoming too large; to fulfil demand for food, man is turning to forest land reserves (required for housing and fuel).
While the total forest area in the (sub) tropics is 858.8 million hectares, only around 15% has a forest management plan, and only 4% is certified (Centrum Hout 2007, ITTO 2004). Around 65% of the total area of certified forest in the tropics falls under the FSC regime (Helpdesk Certified Wood 2008). The largest area of certified forest in the (sub)tropics can be found in Central and South America (12.45 million hectares in January 2008), followed by Asia (5.62 million hectares) and Africa (3.96 million hectares).
About 46% of the total forest area in the (sub)tropics (397.33 million hectares) is used for timber production (plantation and natural forest), of which almost 30% has a forest management plan, and 6.3% is certified (Centrum Hout 2007). Of the total productive area in the (sub)tropics, around 11% (44 million hectares) consists of plantations (FAO 2006) of which 11.1% (4.9 million hectares) is FSC certified (FSC 2008). The combination of the high biodiversity and the high decrease rate of natural forests in tropical areas, largely explains why environmental groups and governments in the West stress the need for guaranteed sustainable production of tropical timber. However, as mentioned above, supply cannot keep up with demand, especially for slow growing tropical hardwood.

In the paragraph above we pointed out that although wood is a renewable material, the sources of this material (forests) are steadily decreasing over time. Especially in tropical regions the total forest area is decreasing rapidly, a.o. due to unsustainable harvesting. The large demand of tropical hardwood because of its good mechanical & aesthetic properties and durability advantages for use outdoors, in combination with the slow growing speed of trees that provide tropical hardwood, makes depletion of especially tropical forests a major problem.

### 1.3.3 Alternatives for Wood: Non Wood Forest Products

Besides wood there are various other renewable resources that can be used to produce semi finished materials. These renewable materials, such as bamboo, rattan, sisal, cork and reed, fall under the umbrella of the term "Non Wood Forest Products" (NWFP). The Food and Agriculture Organization of the United Nations (FAO) defines NWFPs as "products of biological origin other than wood derived from forests, other wooded land and trees outside forests (FAO 2007). The term encompasses all biological materials other than wood which are extracted from forests for human use, including edible and non-edible plant products, edible and non-edible animal products and medicinal products (e.g. honey, nuts, pharmaceutical plants, oils, resins, nuts, mushrooms, rattan, cork)." Although most NWFPs predominantly have value for local trade, some are important export commodities for international trade. Bamboo and rattan are considered the two most important NWFPs (Belcher 1999).

Still, whereas wood as a renewable material has been mass adopted in Western markets, many other renewable materials belonging to the NWFP-group are not well known and can hardly be found in products in these countries, while some of them could have considerable potential to contribute toward sustainable development, both in the country of production and in the country of consumption. In this report the environmental sustainability of bamboo, as one of these relatively unknown renewable materials, is assessed because of its high potential for regeneration and thus also for raw material production.

## 1.4 The Latent Potential of Bamboo

Because of its high growth rate and easy processing, bamboo is a promising renewable resource that could potentially substitute for slow growing hardwood. Bamboo has good mechanical properties, has low costs and is abundantly available in developing countries. Its rapid growth and extensive root network makes bamboo a good carbon fixator, erosion controller and water table preserver. The bamboo plant is an eminent means to start up reforestation, and often has a positive effect on groundwater level and soil improvement through the nutrients in the plant debris.

The greatest advantage of bamboo is undoubtedly its enormous growing speed. Bamboo shoots in tropical countries grow up to 30 meters within six months. The record growth speed measured for a bamboo stem is 1.20 meters per day (Martin 1996), which directly shows the potential of bamboo to substitute slower growing wood species in terms of annual yield.

Due to the high growing speed of bamboo, plantations are expected to be proficient in sequestration of carbon dioxide ($CO_2$). During their growth, plants convert $CO_2$ through photosynthesis into plant carbohydrates, and emit oxygen in the process. The carbon makes up approximately half of the biomass (dry weight) of the renewable raw material. There is an ongoing discussion about the question whether the carbon sequestration capacity of bamboo is larger than that of fast-growing softwood trees. In appendix B this topic is further elaborated upon.

As a result of these features, at an environmental level (Planet), bamboo materials are expected to be environmentally friendly.

Besides the many traditional applications for local markets and low end export markets in which bamboo in its natural form (stem) is usually used, a wealth of new bamboo materials became available since the 1990s through industrial processing, such as Plybamboo and Strand Woven Bamboo, which can be used for applications in high end markets in the West as well. In Figure 1.4 it can be seen how various kinds of bamboo products relate to each other in terms of production technology on the axis traditional - industrial/advanced (bottom of Figure). For more examples of innovative and surprising bamboo applications (e.g. bamboo bikes, bamboo food, and bamboo textile), the reader is referred to van der Lugt (2007).


Figure 1.4: Range of bamboo applications possible, based on traditional and advanced technologies (Larasati 1999)

In this Section, the potential of bamboo will be explored for giant bamboo species from (sub)tropical regions suitable for industrial processing.

### 1.4.1 Industrial Bamboo Materials

Through industrial processing of bamboo virtually anything that can be made from wood can also be developed in industrial bamboo materials. The industrial processing of bamboo and in particular the lamination of bamboo strips into boards (Plybamboo), which is mostly applied in flooring, furniture board, and veneer, started in China in the early 1990s. China is still the leading industrial bamboo producer worldwide and supplies more than 90% of bamboo flooring in Western Europe (van der Lugt and Lobovikov 2008). Besides flooring and board materials, China is also a major producer of woven bamboo mats that can be used, for example, in blinds.
In the past few years, many innovations in the field of production technology have led to the development of new industrial bamboo materials with different properties and possibilities, such as Bamboo Mat Board (BMB), Strand Woven Bamboo (SWB), Bamboo Particle Board, and various experiments with Bamboo Composites.
BMB is made from thin bamboo strips or slivers woven into mats to which resin has been added. Pressed together under high pressure and high temperature, the mats become extremely hard boards, which during pressing can even be put in molds to be processed into corrugated boards.

Figure 1.5: Plybamboo is available in various colors and sizes

Figure 1.6 (left): Coarse woven mats form the building stones for BMB

Figure 1.7 (right): Various kinds of bamboo board material including BMB (right side of picture)

SWB is a new bamboo material made from thin rough bamboo strips that under high pressure are glued in molds into beams. An interesting feature of SWB is that there are no high requirements for input strips which means that, unlike the production of Plybamboo, a large part of the resource can be used, thereby utilizing the high biomass production of bamboo to the maximum (see for more information chapter 3). Due to the compression and addition of resin, SWB has a very high density (approximately 1080 kg/ m3) and hardness, which makes it a material suitable for use in demanding applications (e.g. staircases in department stores). Recently, new higher resin content versions of SWB were developed apt for outside use[9], which could make SWB a suitable alternative for scarce tropical hardwood species such as Bangkirai.

Other new industrial bamboo materials such as Bamboo Particle Board and Bamboo Plastic Composites are still in the earlier stages of development. These materials are based on copying existing techniques from the wood industry, and are not yet widely available commercially. For an overview of available industrial bamboo materials, the reader is referred to Appendix 1 in van der Lugt and Otten (2007).

[9] The latest durability tests executed by SHR (Wood Research Foundation Netherlands) under the commission of Moso International b.v. have revealed that the outdoor version of SWB (higher resin content) falls in durability class I-II (durable - very durable outdoors), which is on par with the most durable tropical hardwood species such as Teak and Azobé. However, the tests were made in laboratory circumstances and focused on the core material and did not include tests on the resistance of the surface of the material to fungi- and UV degradation, nor on the behavior of the material during use. As a consequence more research is still needed about the suitability and competitiveness of SWB for outdoor use (van der Vegte and Zaal 2008).

Figure 1.8: Application of SWB in a stairway

An additional advantage of industrial bamboo materials is that because of the labor-intensive process much value is added. Therefore, industrial bamboo materials can make a greater contribution in terms of employment than the development of products made from the bamboo stem, usually based on handicraft techniques with less value added. The cases of bamboo stem (strong in Planet) and industrial bamboo materials such as Plybamboo (potentially stronger in People and Profit) also provide an excellent example of the conflicting character the various pillars of sustainability (the Triple Bottom line) can have.

Besides the bamboo materials being based on industrial production technologies mentioned above, there is also an array of materials available based on non-industrial technologies. Well known examples of non-industrial bamboo materials are the complete bamboo stem and strips derived from the stem. In the box "Bamboo Stem as a Building Material in the West" in Subsection 9.3.3 in the PhD thesis of van der Lugt 2008, downloadable from the website of INBAR and Delft University of Technology, see link in footnote 1 an introduction about the use of the bamboo stem as a building material can be found. Another material based on a non-industrial technology that can be seen in products in the West is the coiling technique, derived from Vietnam, in which long, thin bamboo slivers are rolled tightly by hand into a mold and then glued together.

Figure 1.9: Coiling is a non industrial processing technique that can create surprising effects; chair design (right) by Jared Huke

### 1.4.2 Bamboo as an Alternative for Hardwood

In the previous Section it was found that an increasing use of renewable raw materials may be necessary to bring down the Ecological Footprint to a sustainable level. However, we also found that at the moment, due to increasing consumption and population numbers, raw material demand is set to increase while supply diminishes. This also applies for timber, as the increasing consumption figures (see Table 1.4), and the decreasing forest areas (see previous Section), especially for tropical timber, show. Also, since emerging economies started to raise their consumption patterns (e.g. China has raised its tropical hardwood import to 7.6 million m3 in 2003, being by far the world's largest importer of tropical logs), the pressure on timber will continue to grow.

Table 1.4: Consumption figures of primary wood products in the EU in 2004, 1000 m3 (ITTO 2004)

| Wood | Total | Growth % 2000-2004 |
|---|---|---|
| Logs | 285,878 | +7 |
| Sawn timber | 88,994 | +6 |
| Plywood | 5,694 | +0 |
| Veneer | 1,753 | +15 |

Due to the expected higher annual yields, and the ability of bamboo plantations to be established on areas of land where trees may not survive (e.g. degraded hill slopes), bamboo may be a promising alternative to help meet the increasing demand in raw materials and timber in particular. Thus bamboo may play an important role at the supply side (area × bioproductivity = biocapacity; see Figure 1.1) of the Ecological Footprint, to meet future human needs for fibers and timber used as input for housing, clothing, interior finishing, furniture, household products and other consumer durables.

Figure 1.10: Bamboo can also grow well on steep slopes

Because of the many hard fibers present in bamboo, industrial bamboo materials such as Plybamboo and SWB in general have competitive mechanical and aesthetic properties to hardwood products and better mechanical properties than softwood (coniferous wood), whereas the annual production volumes are expected to be higher because of the high growth rate of bamboo. Generalizing, it seems to come down to the following: Bamboo grows faster than softwood, but has hardwood properties. Since industrial bamboo materials are still priced more or less at the same level as hardwood

materials (which is higher than most softwoods), the best bet for bamboo is to initially target the markets in which hardwood is used.
In the light of the increasing demand for raw materials, including timber, and the decreasing forest area worldwide, bamboo based materials can therefore serve as an additional alternative to fill the gap between supply and demand of sustainably produced hardwoods. This may apply to both hardwood from temperate and tropical regions, although as seen above, from an environmental point of view it would be best if bamboo could help to meet the demand in tropical hardwood, especially since tropical forests from which this timber is derived are under pressure. This applies in particular to SWB since most tropical hardwood is used in applications outdoors due to its good durability. However, various tropical hardwood species are also used indoors (e.g. Teak) where Plybamboo may also serve as an alternative. In the future some cheaper industrial bamboo products, such as BMB, might be able to compete with softwood.

Besides the development of products for the local market, export markets in the West offer potential markets, especially for industrially produced bamboo materials. In view of the increasing awareness in the West with regard to the necessity of sustainable consumption, there are plenty of possibilities for bamboo to profit from this trend. Furthermore, once bamboo gains a stronger foothold as a potentially sustainable material to be used for products in the West, more trend-following emerging economies such as India and China might follow and will most likely actually acknowledge bamboo as a high end material as well, instead of perceiving it as poor man's timber. It is for these reasons that this report assesses the environmental impact of the use of bamboo materials in products in the West, and in particular on Western Europe as a consuming region.

## 1.5 The Environmental Sustainability of Bamboo

As mentioned in the previous Section, bamboo is often perceived as being environmentally friendly. There are many qualitative arguments, mainly around the biomass production of bamboo, that justify this positive perception. However, many of the industrially produced bamboo materials (Plybamboo, SWB, etc.) go through many energy intensive production steps, produce a lot of waste and are supplemented with many chemical substances (glue, lacquer, etc.). Although the same applies to many wood based products, it does mean that the perceived environmental sustainability of bamboo materials should be questioned.
Therefore, in this report the environmental sustainability of various bamboo materials is determined based on the three environmental problems introduced in Table 1.1 at the "debit" side through calculating their environmental impact or eco-burden (negative environmental effects caused by bamboo materials during their life cycle contributing to the three main environmental problems) using the Eco-costs model developed by

Vogtländer (2001), based on Life Cycle Assessment (LCA) methodology, and at the "credit" side (diminishing the environmental problems) through calculating the regenerative power of bamboo (bioproductivity; see Figure 1.1) through the annual yield. Combined, the environmental impact (debit) and annual yield (credit) can provide an indication of the environmental sustainability of bamboo materials, although the environmental impact calculated through the eco-costs has a broader range than the annual yield (see Table 1.5). Note that the annual yield indirectly has a positive impact on climate change through carbon sequestration (see also appendix B). For an explanation about the relationship between Eco-costs and Ecological Footprint, the reader is referred to Vogtländer (2008).

Table 1.5: Together the eco-costs and annual yield determine to a large extent the environmental sustainability of a material

| Main problem | Debit (-) | Credit (+) |
|---|---|---|
| Depletion of resources | | Exhaustion of food & water |
| | Eco-costs | Exhaustion of energy |
| | Exhaustion of food & water | |
| | Exhaustion of energy | Annual Yield |
| | Exhaustion of raw materials | Exhaustion of raw materials |
| Deterioration of ecosystems | Climate change | Climate change |
| | Erosion | Erosion |
| | Landscape deterioration | Landscape deterioration |
| | Desiccation | Desiccation |
| | Ozone layer deterioration | Ozone layer deterioration |
| | Acidification | Acidification |
| | Spread of dust | Spread of dust |
| | Nuclear accidents | Nuclear accidents |
| | Eutrofication | Eutrofication |
| | Hazardous pollution spread | Hazardous pollution spread |
| Deterioration of human health | Ozone at living level | Ozone at living level |
| | Summer smog | Summer smog |
| | Winter smog | Winter smog |
| | Noise hindrance | Noise hindrance |
| | Stench hindrance | Stench hindrance |
| | Light hindrance | Light hindrance |
| | Indoor pollution | Indoor pollution |
| | Radiation | Radiation |

### 1.5.1 Objective

The main research objective of this report is **to assess the environmental sustainability of various bamboo materials based on use in Western Europe, compared to commonly used material alternatives and in particular timber.**

### 1.5.2 Scope

This report focuses on the use of bamboo materials made from the most commonly used and industrialized giant bamboo species in China: Phyllostachys pubescens (referred to as "Moso" - its local name - in the remainder of this report). Moso is perceived as being one of the bamboo species worldwide with the most commercial potential based on its availability, accessibility and potential for industrialization. Moso bamboo grows abundantly in temperate regions in China, can reach lengths of 10-15 meters and a diameter of 10 centimeters, and is very suitable for industrial processing to develop all kinds of industrial bamboo materials. Since besides Moso there are many other bamboo species (1000-1500 species), the results and findings in this research apply in particular to this species and similar giant bamboo species apt for industrial utilization such as Guadua spp. (referred to as "Guadua" in the remainder of this report) and Dendrocalamus Asper.

Figure 1.11: Guadua is a giant bamboo which grows in clumps mainly in Latin America which may reach heights up to 25 meters

As was shown in Section 1.4, there is a wide array of industrially and non-industrially produced bamboo materials available. The focus in this report is on bamboo materials that are already available in Western Europe, or bamboo materials with potential for the Western European market that are expected to become commercially available on the short to medium term (within ten years): the stem as representative for non industrial bamboo materials, and Plybamboo (board and veneer), Strand Woven Bamboo (SWB), Bamboo Mat Board (BMB) and bamboo composites (fibers) as representatives for industrial bamboo materials. Other, mostly low-end industrial bamboo materials, such as Bamboo Particle Board, are not deemed competitive yet with wood-based boards in the West on the short to medium term. However, for the long term, if production capacity and availability of these materials are improved, they could also become competitive in the West.